

Starter Nitrogen Fertilizer Impact on Soybean Yield and Quality in the Northern Great Plains

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ABSTRACT

Though there have been numerous studies on the effect of nitrogen (N) fertilization on soybean [*Glycine max* (L.) Merr.], relatively few have investigated early season N application in the unique environment of the northern Great Plains. The objective of this research was to investigate the impact of starter N fertilization on soybean yield and quality in this cool environment. To achieve this objective a field experiment was established within a 2-yr corn (*Zea mays* L.)–soybean rotation, using a split-plot design with four replications. Whole plots were tillage [no-tillage (NT) and conventional tillage (CT)] with starter fertilizer (N source by rate) as the split plot treatments. Nitrogen was band applied at planting as either ammonium nitrate (AN) or urea (UR), at rates to supply 0, 8, 16, and 24 kg N ha⁻¹. Yields were greater for the 2004 growing season than 2002 and 2003, possibly due to more favorable environmental conditions. In 2 of the 3 yr there was an increase in grain yield and early (V3–V4 and R1) plant biomass and plant N due to starter N. The initial increase in plant vigor resulted in a grain yield increase compared to the no N treatment. Analysis pooled over the 3 yr of the experiment showed an average yield increase of 6% for the 16 kg N ha⁻¹ rate, compared to the no N treatment, with no difference in grain N or oil concentration. This research demonstrates that applying N as starter has the potential to increase soybean yield and early plant growth, but this may or may not translate into improved grain quality in the unique environments of the northern Great Plains.

ALTHOUGH N fertilization of soybean is not a common practice there is speculation that the ability of soybean to fix atmospheric N is not always adequate for maximum yield (Weber, 1966; Wesley et al., 1998). Researchers have investigated the effect of N fertilizer on soybean yield and quality, but results have been inconclusive. The majority of this research examined application of N during the growing season and was conducted in the central to southern USA where early season soil temperatures are nearly always adequate for microbial activity. While in the northern Great Plains, soil conditions at time of planting and early growth can limit microbial activity and thus potentially delay N fixation and possibly early vegetative growth. There a number of factors influencing soybean N fixation and the response to applied N. Sorensen and Penas (1978) concluded that soil temperature, moisture, and pH affect soybean response to applied N. While Hardy et al. (1971)

determined N fixation begin 14 d after planting only when plants were grown under optimum moisture and temperature conditions, thus a small amount of N at planting could be beneficial to early growth. Bergersen (1958) concluded N applied before planting could be beneficial to soybean, given that nodules were not present until at least 9 d after soybean emergence.

Research conducted in Iowa determined that N applied in a foliar application at approximately V5 (fifth node) increased yield and N uptake but the results were not consistent over time. There were theories that yield increases occurred in areas where soil and/or weather conditions limit soil moisture, reducing early vegetative growth and soil nutrient availability (Haq and Mallarino, 2000). Additional research conducted in Missouri found that out of 48 sites a positive response to N was likely if the following conditions were present: (i) yield levels above 4000 kg ha⁻¹, (ii) fertilizer application at the beginning pod growth stage, (iii) residual soil nitrate less than 85 kg ha⁻¹, (iv) soil pH less than 7.5, and (v) irrigation (Scharf and Wiebold, 2003).

Sij et al. (1979) postulated that a small amount of N applied at planting (“starter N”) would stimulate early vegetative growth. However, research conducted in Texas concluded that N applied at planting had no effect on leaf area, plant height, shoot fresh weight or yield (Sij et al., 1979). Research conduct in Alabama found that broadcasted N increased early soybean vegetative growth 20%, but had no subsequent effect on yield (Terman, 1977). Research by Starling et al. (2000) for soybean following corn in southern Alabama showed that plant growth and grain yield were higher when fertilizer N was applied as starter. Soybean grown in high yielding environments with yield potentials greater than 3500 kg ha⁻¹ had a positive response to N when applied at early flowering, compared to early pod-fill (Flannery, 1986; Wesley et al., 1998). Brevedan et al. (1978) reported a 28 to 33% yield increase if N was applied between initial bloom (R1) to the end of bloom (R3) for soybean grown in a greenhouse.

Field research conducted in Kansas found that application of N at the beginning pod growth stage increased yield at four irrigated sites, but had no effect on grain protein or oil concentration (Wesley et al., 1999). In contrast, research conducted in the cooler environment (relative to the southern USA) of Minnesota found that preplant broadcast N application increased soybean yield, weight per seed and seed protein, but had no effect on seed oil concentration (Ham et al., 1975). Further research in Minnesota found that application of N in-season did not alter soybean yields or oil

USDA-ARS, North Central Agricultural Research Lab., 2923 Medary Ave., Brookings, SD 57006. Mention of trade name or commercial products in this publication is solely of the purpose for providing specific information and does not imply recommendation or endorsement by the USDA. Received 26 Mar. 2006. *Corresponding author (sosborne@ngirl.ars.usda.gov).

Published in Agron. J. 98:1569–1574 (2006).

Fertilizer Management

doi:10.2134/agronj2006.0089

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677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: AN, ammonium nitrate; CT, conventional tillage; NT, no tillage; UR, urea.

concentration, and the affect on protein was minimal (Schmitt et al., 2001).

Researchers in South Dakota found that N broadcast on the soil surface at planting or at soybean emergence increased yield, while N applied at midpod fill did not increase yield (Bly et al., 1998; Riedell et al., 1998; Woodard et al., 1998). Additional research in the northern Great Plains found low rates ($<15 \text{ kg N ha}^{-1}$) of starter N increased soybean yield compared with no N applied at planting in 9 out of 11 yr but could not speculate to reasons for this increase in yield (Pikul et al., 2001). They concluded that additional research needed to be conducted to investigate the reason for the increase in yield.

Considering that N response is related to growing season environment, the objective of this study was to determine the impact of starter fertilizer N rates and sources on soybean yield and quality in cool environments of the northern Great Plains.

MATERIALS AND METHODS

A corn–soybean rotation experiment was established in the spring of 2000 at the Eastern South Dakota Soil and Water Research Farm near Brookings, SD. Soil types included Barnes clay loam (fine-loamy, mixed, superactive, frigid Calcic Hapludolls), and Vienna-Brookings complex (Vienna- fine-loamy, mixed, superactive, frigid Calcic Hapludolls; Brookings- fine-silty, mixed, superactive, frigid Aquic Hapludolls). Initial surface (0–15 cm) soil test characteristics showed a soil pH of 6.3 (1:1 soil/water paste), 2.9% organic matter (determined by loss-on-ignition) (Cambardella et al., 2001), extractable P and exchangeable K of 5 and 181 mg kg^{-1} , respectively. Initial subsurface (15–30 cm) soil test characteristics showed a soil pH of 6.96, 2.1% organic matter, extractable P and exchangeable K of 2 and 159 mg kg^{-1} , respectively. Initial soil test characteristics were determined by the South Dakota State Soil Testing Laboratory, Brookings, SD (Gelderman et al., 1995). Extractable P (Olsen P) was determined using the NaHCO_3 method (Olsen et al., 1954). Exchangeable K was determined using the NH_4Ac method (Brown and Warncke, 1988).

The experiment was conducted as a split-plot design with four replications. Each phase of the rotation was present each year. Whole plots were tillage (NT and CT) and the split plots were fertilizer (source \times rate) treatments. Conventional tillage was performed with a chisel plow in the fall of each year, with seedbed preparation in the spring using a field cultivator and crop cultivation performed in early July. No-tillage plots were established with tillage ending in the spring of 2000 before soybean planting. Starter fertilizer treatments (N source, N rates) were arranged in a 2×4 complete factorial within each tillage system main plot. Ammonium nitrate (34–0–0) and urea (46–0–0) were the N sources applied at rates to supply 0, 8, 16, and 24 kg N ha^{-1} . Phosphorus and K were applied at planting to each plot at 17 kg P ha^{-1} as triple super-phosphate (0–36–0) and 12 kg K ha^{-1} as KCl (0–0–60). All fertilizer was applied at planting in band (5 cm below and 5 cm to the side of the seed furrow). Plots were 6 by 15 m with a 0.76-m row spacing (8 rows). The corn phase of the rotation received the same starter fertilizer treatments as that designated for the particular treatment for the soybean phase. Soybean and corn treatments were located on the same experimental plot every other year. Corn in the rotation was sidedressed with 85 kg N ha^{-1} as AN at the V6 (six collared leaves) growth stage. The previous crop, before establishing the experiment, was corn. Data collection started in 2002 following one full rotation cycle.

Pioneer variety 91B01 (maturity 1.0) soybean were seeded at a rate of 590 000 seeds ha^{-1} . Soybean were planted using a John Deere planter with residue managers. Soybean plants were inoculated with *Bradyrhizobium japonicum* at the time of planting. ‘Bentazon’ [3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide] 42% active ingredient and ‘Pinnacle’ [3-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid] 25% active ingredient were applied pre-emergence to all plots at a rates of 0.29 and 0.003 L ha^{-1} , respectively. Crop planting, tillage, herbicide application, plant sampling, harvest and soil sampling dates are reported in Table 1.

Whole plant samples were collected three times during the growing season by taking 1 m of row. Samples were collected at V3–V4 (third, fourth node), R1 (beginning bloom), and R3 (beginning pod). Plant phenology data was collected weekly from the first of June until the end of August, according to Ritchie et al. (1996). All samples were dried for 120 h in a forced-air oven at 60°C , weighed, and ground to pass a 2-mm sieve. Plant N concentration was determined on all samples using dry combustion techniques (Schepers et al., 1989).

Grain yield was determined by harvesting 15 m of the center two rows from each plot using a plot combine (Massey Ferguson, Haven, KS). Grain moisture and test weight were determined. Soybean grain yield was adjusted to 130 g kg^{-1} moisture. Grain samples were oven-dried at 60°C , ground to pass a 2-mm mesh sieve, and analyzed for N concentration using dry combustion (Schepers et al., 1989). Whole seed analysis for oil concentration was determined using near infrared reflectance spectroscopy (Foss, NIRSystems, Model 5000, Eden Prairie, MN). Calibration equations used to determine oil concentration have a standard error of 0.05% (Cho et al., 1998).

Soil samples were collected in early spring before seedbed preparation each year for each plot (Table 1). Two soil cores per plot (4.45-cm diam.) were taken and composite to a depth of 60 cm and split into four increments: 0 to 15, 15 to 30, 30 to 45, and 45 to 60 cm. Soil samples were air-dried at ambient temperature and ground to pass a 2-mm screen. Samples were extracted using 2 M KCl (Bremner, 1965) and analyzed for $\text{NO}_3\text{-N}$ using automated flow injection analysis (Lachat Instruments, 1989). Data analysis was performed using the Proc Mixed procedure in SAS (SAS Institute, 1999) utilizing $\alpha = 0.05$.

RESULTS AND DISCUSSION

The unique environmental conditions in the northern Great Plains are such that soil temperatures are colder at planting, additionally adoption of NT soil management practices could delay soil warming (Shinners et al., 1993; van Wijk et al., 1959). Therefore it was speculated

Table 1. Planting, cultivation, herbicide application, plant sampling, harvest, and soil sampling dates, Brookings, SD, 2002–2004.

Agronomic practice	2002	2003	2004
Fall chisel†	5 Nov.	11 Nov.	3 Nov.
Soil sampling	6 May	14 Apr.	4 May
Seedbed tillage†	13 May	28 Apr.	11 May
Planting	15 May	13 May	13 May
V3–V4 biomass	24 June	26 June	1 July
R1 biomass	1 July	2 July	12 July
R3 biomass	15 July	18 July	22 July
Herbicide application	12 June	16 June	17 June
Cultivation§	24 June	2 July	8 July
Harvest	24 Sept.	23 Sept.	5 Oct.

† Conventional tillage treatment.

‡ Performed the previous fall.

§ Performed in season.

Table 2. Soybean grain yield, significance levels for treatment and treatment interactions, using a mixed model, Brookings, SD, 2002–2004.

		Grain yield, kg ha ⁻¹			
Source	df†	2002	2003	2004	Pooled
<i>Pr</i> > <i>F</i> ‡					
Tillage	1	0.6336	0.6453	0.2248	0.4319
N rate	3	0.0683	0.0051	0.0084	0.0014
Tillage × N rate	3	0.7546	0.2694	0.3614	0.5410
Source	1	0.7480	0.7925	0.3386	0.5817
Tillage × source	1	0.1104	0.8355	0.0102	0.3777
N Rate × source	3	0.4973	0.5782	0.0206	0.1099
Tillage × N rate × source	3	0.7123	0.1417	0.0825	0.2590

† df, degrees of freedom.

‡ *Pr* > *F*, probability of obtaining a greater *F* value.

that the application of starter fertilizer would be more beneficial in NT compared to CT management. The main effects of tillage and N source did not affect plant biomass or grain yield for any of the 3 yr of the experiment (Table 2).

There were differences among years for grain yield ($P < 0.0001$) with the largest yield during 2004 (2260 kg ha⁻¹) compared with the 2002 (1354 kg ha⁻¹) and 2003 (1873 kg ha⁻¹) growing seasons. The lowest yield was obtained during the 2002 growing season (Fig. 1); this low yield could be due to differences in precipitation throughout the growing season (Table 3). In 2 of the 3 yr there were increases ($\alpha < 0.05$) in grain yield due to starter fertilizer application (Table 2 and Fig. 1). The 16 kg N ha⁻¹ treatment produced the maximum yield in 2002 and 2004 and for the pooled analysis. Average yield increase for this treatment was greater than 5% compared to the no N treatment (7.2, 5.3, 6.2, and 6.1% for 2002, 2003, 2004, and pooled analysis, respectively).

There was no effect of N rate treatment in the 2002 growing season (*Pr* > *F* value of 0.0683, Table 3). In contrast, previous research conducted by Pikul et al. (2001) found that soybean yield increased with low rate

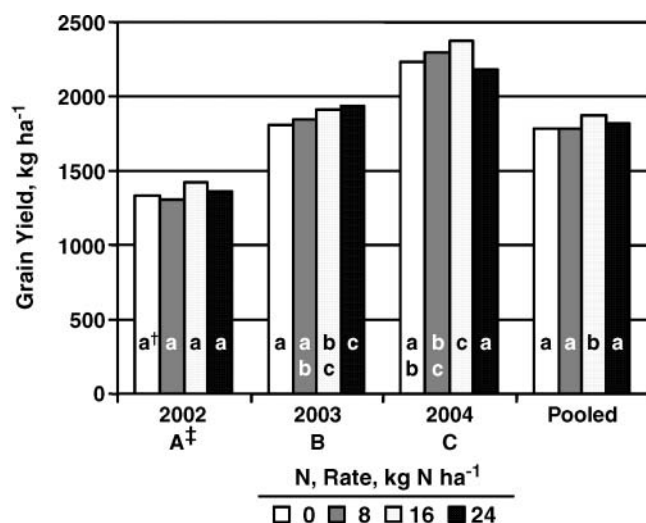


Fig. 1. Soybean grain yield response to N rate averaged over N source and tillage treatments, Brookings, SD, 2002–2004 († Different letters indicate significant differences in N rate within years and pooled over years at the 0.05 probability level. ‡ Different letters indicate significant differences among years at the 0.05 probability level).

Table 3. Average monthly temperature, total monthly precipitation, and pan evaporation, Brookings, SD, 2002–2004.†

Month	2002			2003			2004		
	Temp. °C	Precip. mm	Evap. mm	Temp. °C	Precip. mm	Evap. mm	Temp. °C	Precip. mm	Evap. mm
April	6.1 (-0.3)†	34 (-19)	205 (12)	7.8 (1.4)	49 (-4)	153 (1.4)	4.1 (-2.4)	41 (-12)	179 (-14)
May	10.9 (-2.1)	78 (4)	204 (-20)	12.8 (-0.2)	69 (-5)	198 (-40)	9.1 (-3.9)	158 (84)	159 (-65)
June	20.8 (2.3)	62 (-44)	231 (-7)	18.3 (-0.2)	84 (-22)	244 (6)	15.0 (-8.0)	75 (-31)	197 (-41)
July	24.0 (2.6)	71 (-8)	183 (109)	20.0 (-1.4)	70 (-8)	214 (6)	17.7 (-9.0)	111 (32)	140 (-68)
August	20.2 (0.1)	183 (109)	172 (-36)	21.7 (1.6)	56 (-18)	809	14.6 (-5.7)	29 (-45)	
Total		428	812		328	-481		675	
Total deficit			-384					-261	

† Numbers with parenthesis represent the deviation from the 30-yr average.

of N applied at planting. This lack of a significant response in our study could be attributed to the large variability in yield during the 2002 growing season as the standard deviation about the N rate treatment mean was 8 to 9% compared with 4 to 5% standard deviation for 2003 and 2004.

We speculate that the large variability and the lower grain yield for the 2002 season were largely due to the growing environment during the months of June and July; precipitation was low during this time with unseasonably high temperatures compared to the 30 yr average (Table 2). Previous research has demonstrated that during periods of drought stress N_2 fixation is the first to decrease compared to other physiological processes (Durand et al., 1987; Sall and Sinclair, 1991; Sinclair et al., 1987). A possible decrease in N_2 fixation could have contributed to the low yields in 2002.

There was no treatment interaction for the first 2 yr (2002 and 2003) for the study. During the 2004 growing season there was a tillage \times N source and N rate \times N source interaction (Table 2). The tillage \times N source interaction was due to a difference among soybean yields in the NT treatment with the UR treatment having a greater grain yield (2297 kg ha⁻¹) than the AN treatment (2160 kg ha⁻¹), while there was no difference in yield between N sources within the CT treatment. The interaction between N rate and source occurred because application of UR at 16 kg N ha⁻¹ increased yield compared to the other treatments (Fig. 2).

Proponents of starter fertilizer believe that a small amount of fertilizer placed near the seed can increase soybean growth early in the season when unfavorable environmental conditions exist (Sij et al., 1979). Unfavorable conditions, such as cool climates or NT soil management, can lead to excessively cool soil temperatures thus delaying N fixation (Hardy et al., 1971). To address this issue plant biomass samples were collected at three different growth stages (V3–V4, R1 and R3).

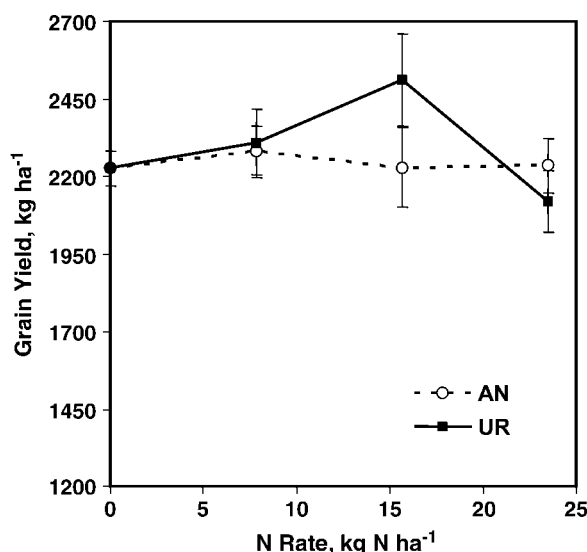


Fig. 2. Soybean yield response to N rate and N sources averaged over tillage, Brookings, SD, 2004 (AN, ammonium nitrate; UR, urea).

Results showed that there were only those differences in plant biomass and plant N due to N rate (Table 4), therefore the discussion will include only differences due to N rate averaged over tillage and N source for the pooled 3-yr analysis (analysis among years did not show a difference between years). There was a linear increase in plant biomass with starter N application, and an increase in in-season plant N for the first two sampling dates, while the later sampling date (R3) did not show a response to starter N when both plant biomass and plant N were measured (Table 4). It is likely that the plant would be utilizing N from translocation within the plant at this growth stage.

Preplant soil samples were collected and analyzed to determine the amount of residual soil NO_3-N . There was no difference in residual soil NO_3-N (0–30 cm) in any of the growing seasons with the average level of residual soil NO_3-N less than 20 kg ha⁻¹ (data not shown). Previous research documented yield responses to fertilizer N when soil NO_3-N was less than 85 kg ha⁻¹ (Stone et al., 1985; Scharf and Wiebold, 2003), therefore, because residual soil NO_3-N levels did not exceed 50 kg ha⁻¹ in the top 0 to 60 cm across all treatments in our study, it is likely that the yield response was due to fertilizer application not residual soil NO_3-N .

Soybean seed N and oil concentrations were measured as an estimate of soybean seed composition. Treatment effects on grain N and oil concentration were inconsistent among the different growing seasons. There was a difference in grain N due to tillage for the 2002 and 2004 growing seasons, but no difference in 2003. The CT treatment had a higher grain N concentration compared with the NT treatment. The pooled analysis, over years, did not show any response due to any of the treatments for grain N or oil concentration (Table 5). There was a response due to starter N for the 2002 growing season for oil concentration; generally decreasing with starter N application for the NT treatment (Fig. 3), while only the 24 kg N ha⁻¹ rate decreased oil concentration for the CT treatment. Previous research conducted in different environmental conditions have found similar nonconclusive results for soybean quality mea-

Table 4. Early season plant biomass, and plant N in response to applied N, Brookings, SD, 2002–2004. Each value represents an average of 3 yr, four replications two tillage and N sources.

N rate	V3–V4	R1	R3
kg N ha ⁻¹		Biomass, kg ha ⁻¹	
0	244	425	1341
8	246	457	1291
16	261	500	1353
24	279	493	1429
<i>Pr</i> > <i>F</i> †	0.0025	0.0002	0.0843
Linear‡	0.0003	0.0001	0.0574
		Plant N, mg kg ⁻¹	
0	3.42	4.13	3.48
8	3.61	4.04	3.40
16	3.70	3.99	3.42
24	3.80	4.16	3.41
<i>Pr</i> > <i>F</i>	0.0001	0.0001	0.3020
Linear	0.0001	0.6075	0.2229

† Probability of a significant response to applied N.

‡ Probability of a linear response to applied N.

Table 5. Soybean grain N concentration and oil concentration, significance levels for treatment and treatment interactions, using a mixed model, Brookings, SD, 2002–2004.

		N, g kg ⁻¹				Oil, g kg ⁻¹			
Source	df†	2002	2003	2004	Pooled	2002	2003	2004	Pooled
<i>Pr > F‡</i>									
Tillage	1	0.0355	0.7745	0.0310	0.9582	0.0939	0.8894	0.0105	0.6279
N rate	3	0.6821	0.4329	0.4313	0.6129	0.0001	0.1103	0.1207	0.0882
Tillage × N rate	3	0.1378	0.5698	0.1188	0.7545	0.0013	0.4001	0.4267	0.2071
Source	1	0.3302	0.1603	0.6560	0.5638	0.2789	0.4506	0.8662	0.8425
Tillage × source	1	0.1936	0.1676	0.6210	0.7169	0.2105	0.1479	0.4069	0.9800
N rate × source	3	0.1837	0.6245	0.8808	0.7130	0.5920	0.6720	0.8884	0.8824
Tillage × N rate × source	3	0.3983	0.0710	0.7899	0.1432	0.8321	0.8028	0.8283	0.9223

† df, degrees of freedom.

‡ *Pr > F*, probability of obtaining a greater *F* value.

surements and N fertilization (Barker and Sawyer, 2005; Wesley et al., 1998).

CONCLUSIONS

Environmental conditions during the growing season appeared to impact overall grain yield, with 2004 having the highest yield and 2002 having the lowest. Grain yield was increased by application of starter N in two (2003 and 2004) out of the 3 yr, with a similar, although not statistically significant, trend in 2002, with an average increase greater than 5% for the 16 kg N ha⁻¹, rate compared to the no N treatment. This increase in grain yield could be due to an increase in early plant biomass (V3–V4 and R1) and plant N. Starter fertilizer application had a positive impact on early plant biomass and plant N although this increase in plant growth did not continue to the later sampling date (R3). Grain quality data (grain N and oil concentration) showed inconsistent results for the 3 yr of this study, possibly due to differences in growing environment. There were no differences in grain N or oil concentration for the pooled analysis. The small difference in yield obtained in this study may not be sufficient to offset additional fertilizer cost. However, it is important to note that application

of starter is within the current management practice, thus that the additional cost of adding N to a P and K starter application is minimal.

ACKNOWLEDGMENTS

The authors thank Kurt Dagel, Dave Schneider, and Max Pravecek for careful management of research plots, data collection, and analysis for this study. USDA offers its programs to all eligible persons regardless of race, color, age, sex, or national origin.

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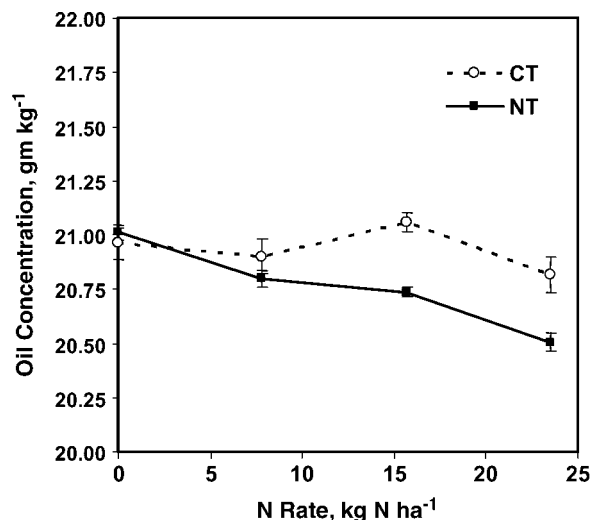


Fig. 3. Soybean oil concentration response to N rate and tillage averaged over N sources, Brookings, SD, 2002 (CT, conventional tillage; NT, no tillage).

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